THE EFFECT OF WEATHER UPON THE YIELD OF POTATOES.

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CONTENTS.

INTRODUCTION.

Potatoes are a cool-weather crop, and undoubtedly originated in the mountains of South America. The first mention of this plant was in a Spanish history of Peru, in 1550, where it was stated that the natives near Quito cultivated it.

In 1897, in going from Callao to Oroya, Peru, Prof. R. DeC. Ward noticed in a region at an elevation of 10,500 feet above sea level a district that is famous for its potatoes and where little else is grown. Ward states that the first part of his journey over this remarkable railroad was through fields of sugar cane and cotton where the elevation was but little above sea level. At 5,000 feet elevation a zone of fruit trees was passed through, at 10,500 feet the potato district, and at a still higher elevation only grass was found.

While this region is nearly under the equator the mountain districts are cool. At Cuzco, the old capital of the Incas, the average annual temperature is only 52° F. and varies from 48° in July to 54° in November. This place is 11,100 feet above sea level and is only slightly higher than the potato district mentioned by Ward.

Figure 1 and Table 1 show that in the United States the potato has made its greatest development in the cooler sections of the country where the mean annual temperature is between 40° and 50° and where the mean temperature of July is not over 70°. Further, the greatest yields of potatoes per acre, as shown in figure 2, are in those States where the mean annual temperature is below 45° and where the mean of the warmest month is not far from 65°.

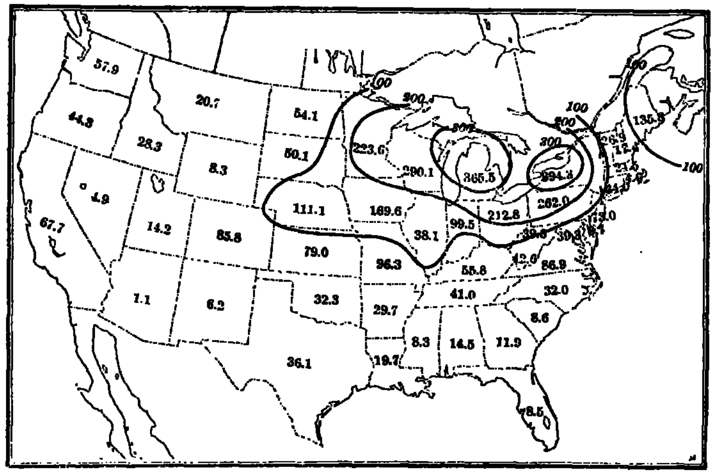

FIG. 1.—Number of thousands of acres planted to potatoes in each State in 1909. (Based on U. S. census reports.)

TABLE 1.—*Potato acreage, by States, in 1909, based on United States census.*

State.	Acreage.	State.	Acreage.
Alabama	14,486	Nebraska	111,151
Arizona	1,151	Nevada	4,864
Arkansas	29,719	New Hampshire	17,370
California	67,688	New Jersey	72,991
Colorado	85,839	New Mexico	6,230
Connecticut	23,959	New York	394,319
Delaware	9,703	North Carolina	31,990
Florida	8,509	North Dakota	54,067
Georgia	11,877	Ohio	212,808
Idaho	28,341	Oklahoma	32,295
Illinois	138,052	Oregon	44,265
Indiana	99,504	Pennsylvania	262,013
Iowa	169,567	Rhode Island	4,649
Kansas	79,025	South Carolina	8,610
Kentucky	55,750	South Dakota	50,052
Louisiana	19,655	Tennessee	40,963
Maine	135,799	Texas	36,092
Maryland	39,299	Utah	14,210
Massachusetts	24,459	Vermont	26,859
Michigan	365,487	Virginia	86,927
Minnesota	223,692	Washington	57,897
Mississippi	8,342	West Virginia	42,621
Missouri	96,259	Wisconsin	290,185
Montana	20,710	Wyoming	8,333

Yield.—The area devoted to potatoes in the United States in 1912 was 3,711,000 acres. The number of bushels produced that year was 420,647,000, the farm value of which was $212,550,000 on December 1.

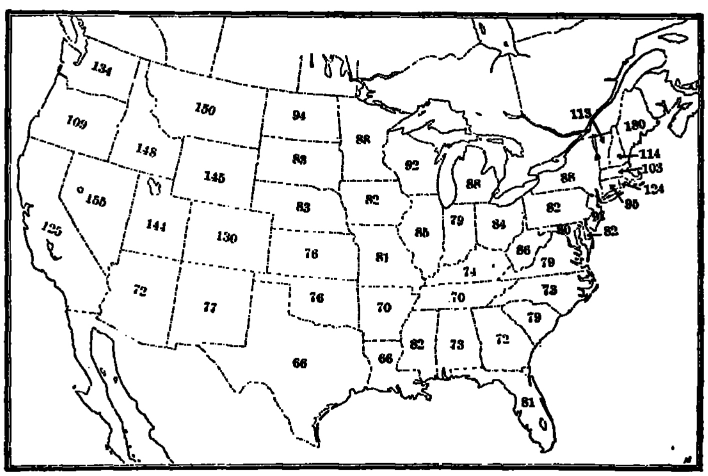

FIG. 2.—Average yield of potatoes, in bushels per acre, in each State for 1900–1909. (U.S. Dept. Agric. Yearbook for 1913.)

In figure 1 the number of thousands of acres planted to potatoes in each of the United States in 1909 is given.

While this chart does not take into consideration the variation in size of the different States, it would present much the same appearance if it should show the production per square mile of area. The greatest proportion of Irish potatoes is grown in the northeastern quadrant of the United States.

In figure 2 the yield of potatoes in bushels per acre is shown for each State for the 10 years, 1900 to 1909, inclusive. The yield in Maine was 180 bushels per acre, while in the central Rocky Mountain States it was over 140 bushels per acre.

In Ohio potatoes rank fourth in importance in the staple crops, corn being first, oats second, and wheat third. The acreage devoted to potatoes in Ohio in 1912 was 104,812 and the yield was 10,579,701 bushels. Fully one-half of the potatoes produced in Ohio are grown in the northeast quarter of the State.

The mean annual temperature for the northern third of Ohio is 49.4° and the mean temperature for the warmest month is 72.5°.

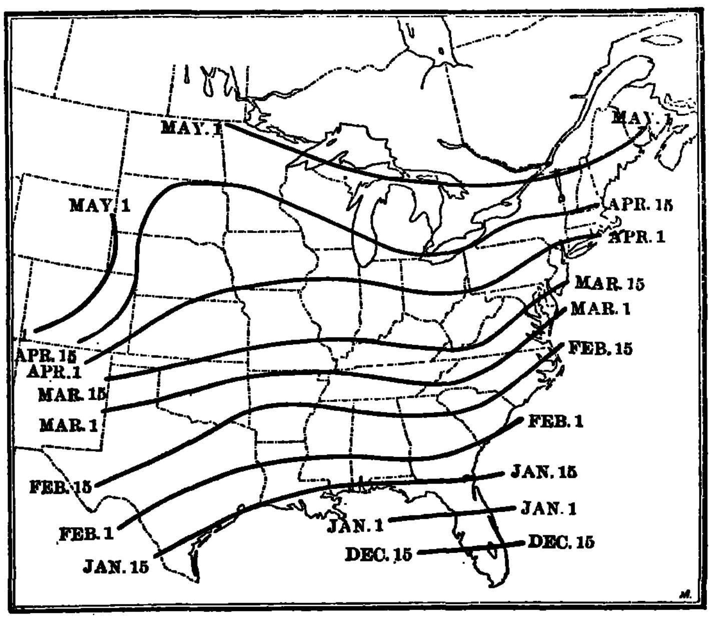

FIG. 3.—Average date on which planting of early potatoes begins. (U. S. Bureau of Crop Estimates.)

Dates of planting and harvesting potatoes.—In studying the effect of the weather upon the growth and development of any plant it is necessary to know the season during which it is making its best growth.

In figures 3 and 4, therefore, the average dates when *early* potatoes are planted and when dug are indicated. Figure 3 shows that early potatoes are planted in southern Florida in December and along the Gulf coast early in January. The time of the beginning of planting then progresses with a fair degree of regularity northward until it is the 1st of May in Upper Michigan and northern Maine. The effect of the Appalachian Mountains and of the cool waters of the Lakes in delaying planting is plainly indicated.

The harvesting of early potatoes, as shown in figure 4, begins in March in southern Florida, and about September 1 in northern Maine. From these two charts figure 5 was prepared, which gives the total number of days necessary for the growth of early potatoes in different sections of the country east of the Rocky Mountains. The greatest number of days between the beginning of planting and digging is seen to be across the central part of the country and in northern Maine. The least number of days is 76 in northeastern Ohio.

In figures 6, 7, and 8 similar charts are given to show the *time of planting, time of digging,* and the days necessary for the growth and development of *late* potatoes. It will be at once noted that while the planting and dig-

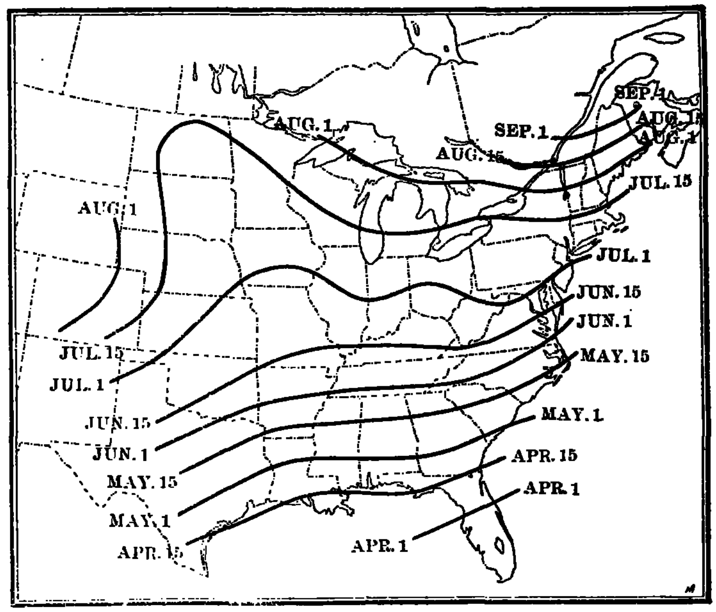

FIG. 4.—Average date on which digging of early potatoes begins. (U. S. Bureau of Crop Estimates.)

ging of early potatoes progresses from south to north similar work on the late potato crop progresses from the north southward.

The earliest date for the beginning of planting late potatoes is April 20 in the vicinity of New York, and the

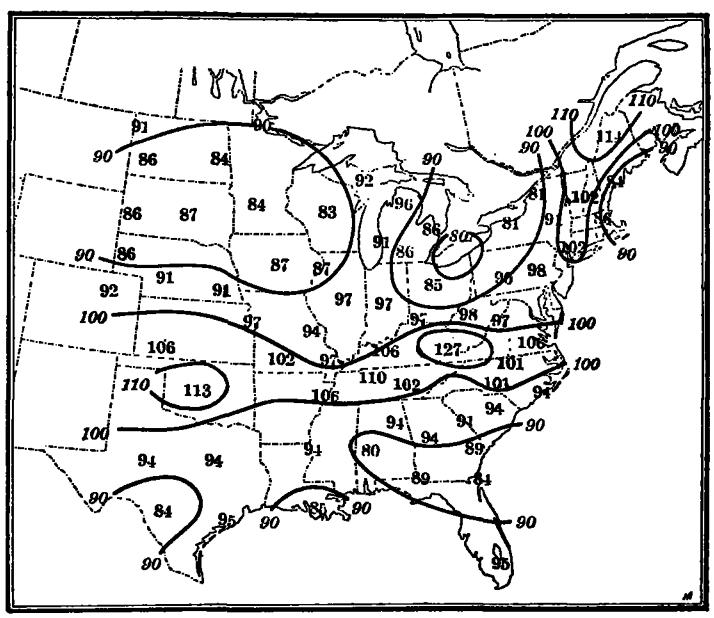

FIG. 5.—Average number of days between planting and digging early potatoes.

latest date December 1 at Miami, Fla. The digging of late potatoes begins in September in the extreme northeast, in the vicinity of Chicago, and in the central Appalachian Mountain district. In extreme southern Florida late potatoes are not dug until the first of February.

One interesting feature in figure 8 is that while the number of days for the growth of late potatoes is greater than it is for early potatoes in the northern part of the United States, it is not so great in southern States. Another is that the higher elevations in Virginia and

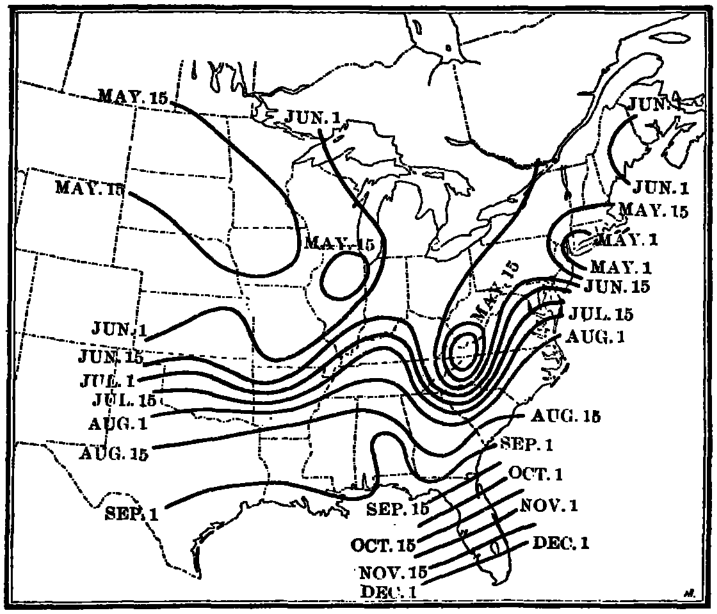

FIG. 6.—Average date on which planting of late potatoes begins. (U. S. Bureau of Crop Estimates.)

North Carolina partake of the characteristics of the more northern districts, probably because of the similarity in temperature.

On the chart in figure 9 there has been entered the mean daily temperature for the date when the planting

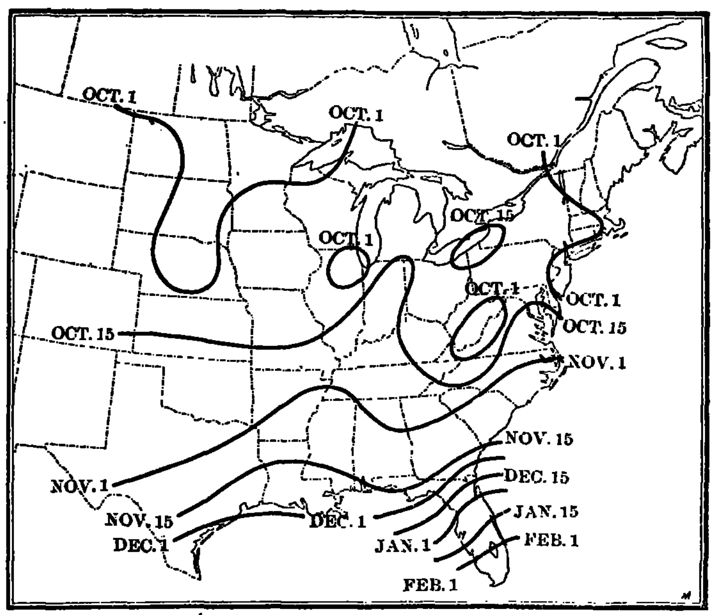

FIG. 7.—Average date on which digging of late potatoes begins. (U. S. Bureau of Crop Estimates.)

of early potatoes begins. This shows that whether the date of planting is February 15 in northern Georgia or May 1 in the northern portion of the United States the seasonal rise has brought the temperature close to 45°F.

When the mean temperature value is much lower than this, as at New York, it is apparent that the earlier planting date is local and possibly artificial and is slightly earlier than the average for that section of the country. Also when the temperature is much higher than 45°, as at Albany, N. Y., the average date of planting may be slightly later than a further investigation of planting

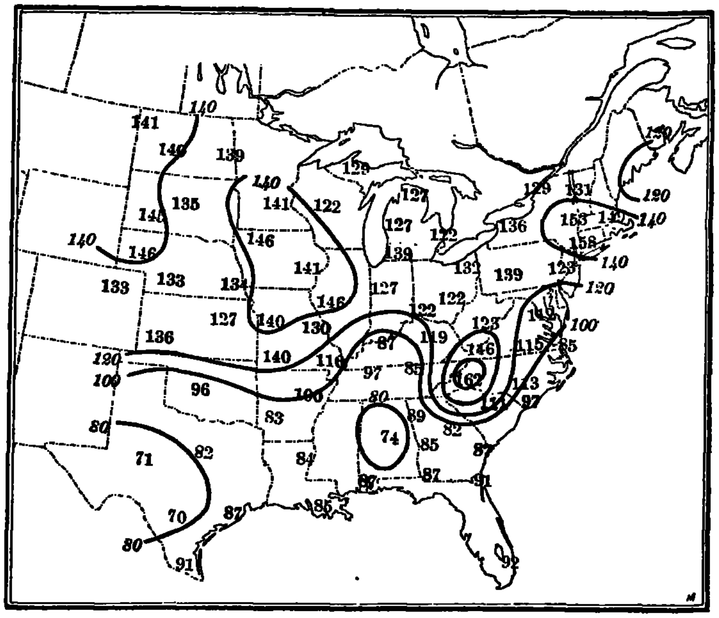

FIG. 8.—Average number of days between planting and digging late potatoes.

dates would place it. It is an interesting fact that the normal daily temperature on the average date of the beginning of planting corn is 55°.

The mean temperature is above 45° in the extreme southern portion of the United States when early potatoes are planted because the normal daily temperature does not reach so low as that in any season of the year.

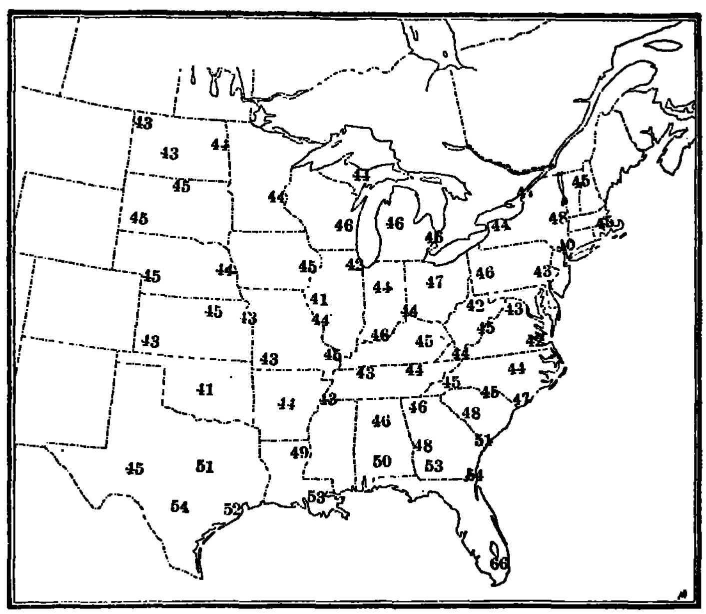

FIG. 9.—Mean daily temperature (°F.) on the date when the planting of early potatoes begins.

The average daily temperature on the date that late potatoes are planted, as shown by figure 10, indicates no such uniform value as is the case with early potatoes. One interesting thing, however, is that while the planting of late potatoes is much earlier in the high altitude districts of Virginia and North Carolina than at other places in that latitude, the daily temperature at the time of planting is lower than at nearby lower-altitude points and agrees with the temperatures in the northern portions of the country.

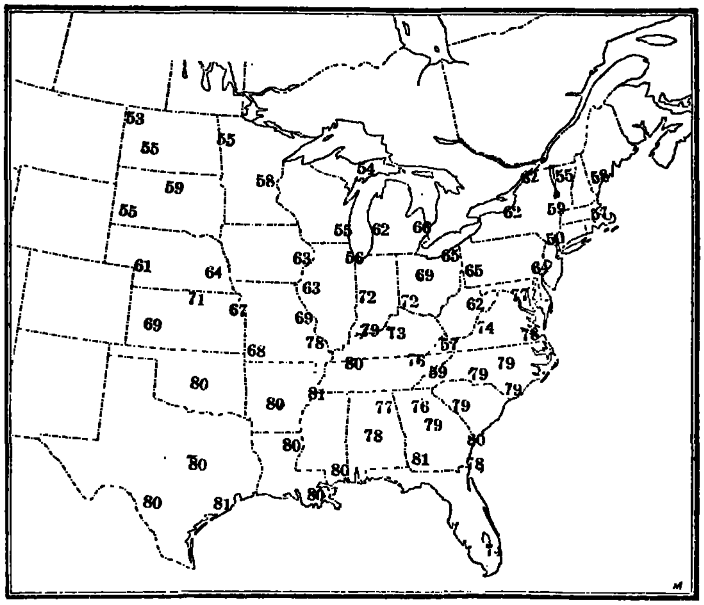

Fig. 10.—Mean daily temperature (°F.) on the date when the planting of late potatoes begins.

Frost dates.—Figure 11 shows the average dates of the last killing frost in the spring in central and eastern United States. A comparison with figure 3 indicates that the last killing frost in the spring occurs, on an average, about one month after early potatoes are

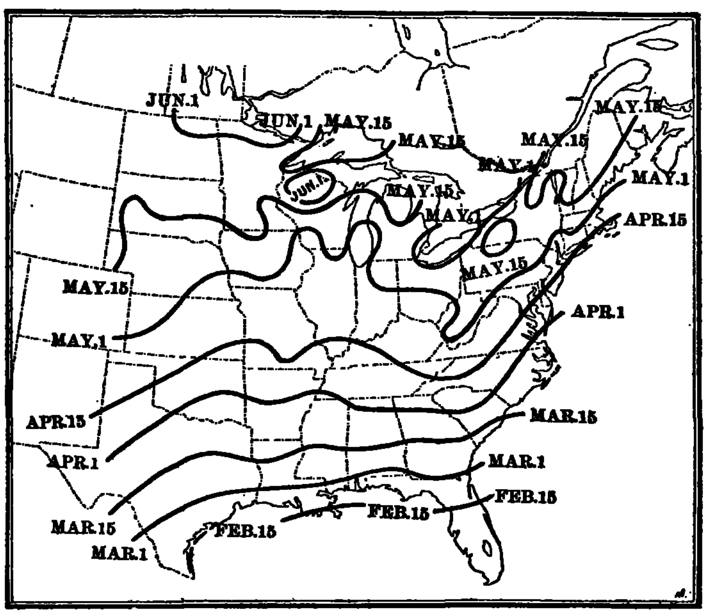

Fig. 11.—Average date of last killing frost in spring. (From Weather Bureau bulletin V.)

planted. In Table 16 it is shown that the average time that it takes early potatoes to come up, at Wauseon, Ohio, is 17 days. This indicates that early potatoes are very apt to be cut back by frost.

In figure 12 there is given the average dates of the first killing frost in the fall. This agrees very closely with the beginning of digging of late potatoes as shown in figure 7, as would be expected.

WATER REQUIREMENTS OF POTATOES.

Water requirements of potatoes.—A rainfall of 1 inch means a fall of 6,272,640 cubic inches of water on 1 acre of land, which equals 3,630 cubic feet or 27,154 gallons per acre. As 1 gallon of water at 62° F. weighs 8.3 pounds (U. S. measure), the weight of 1 inch of water on 1 acre of land would be 225,378 pounds or 112.7 tons. One inch of rain on 1 square mile of land is equal to 2,323,200 cubic feet of water.

Prof. Charles D. Woods, of the Maine Experiment Station, states that it has been found by experiment it takes about 425 tons of water to grow 1 ton of dry matter of potatoes, and therefore that a crop of 200 bushels per acre would require approximately 650 tons of water. This would be equivalent to a rainfall of nearly 6 inches. The Ohio Farmer states that it requires over 108,000 gallons of water to mature a single acre of potatoes, or slightly over 4 inches of rain.

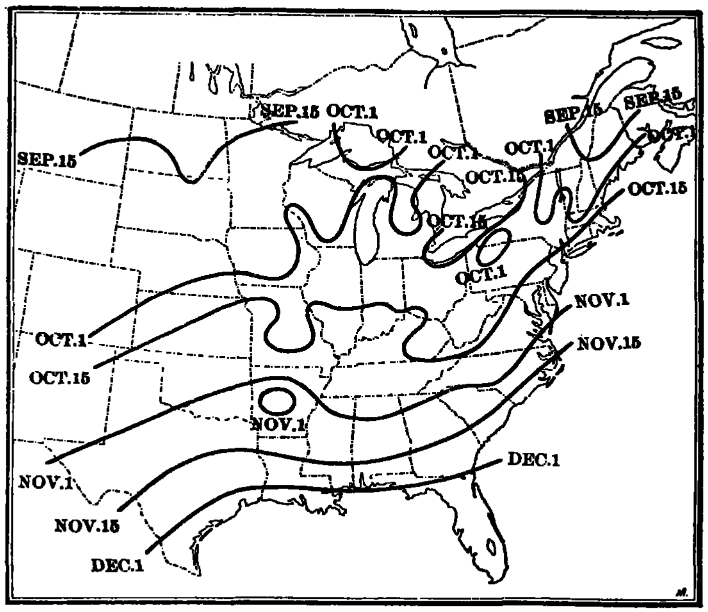

Fig. 12.—Average date of first killing frost in autumn. (From Weather Bureau bulletin V.)

Briggs and Shantz, in investigations made in northeastern Colorado in 1911, determined that the ratio of the weight of water absorbed during the growth of potatoes to the weight of dry matter produced was 448. The variety of potato used in the experiment was the Irish Cobbler.

This water requirement is sometimes called the "transpiration ratio" and represents the amount of water transpired by the plant. It does not take into account the water from a rainfall that may run off from the surface of the ground or that is lost by seepage or surface evaporation.

The amount of water transpired by a crop varies with temperature and humidity of the atmosphere, the wind velocity, sunshine, and the condition of the soil; also the size of the plants themselves, and the amount of moisture available in the soil.

King, in the more humid climate of Wisconsin, in 1892–1895, found that it required only 423 tons of water to produce 1 ton of dry matter of potatoes. Von Seelhorst, in 1896–1898, at Göttingen, Germany, found the water requirement of potatoes to be only 281, but the experiments of Widtsoe, at Logan, Utah, agree very closely with those of Briggs and Shantz in Colorado.

In one experiment in Utah it was found that with an application of water at the rate of 9 inches the yield was

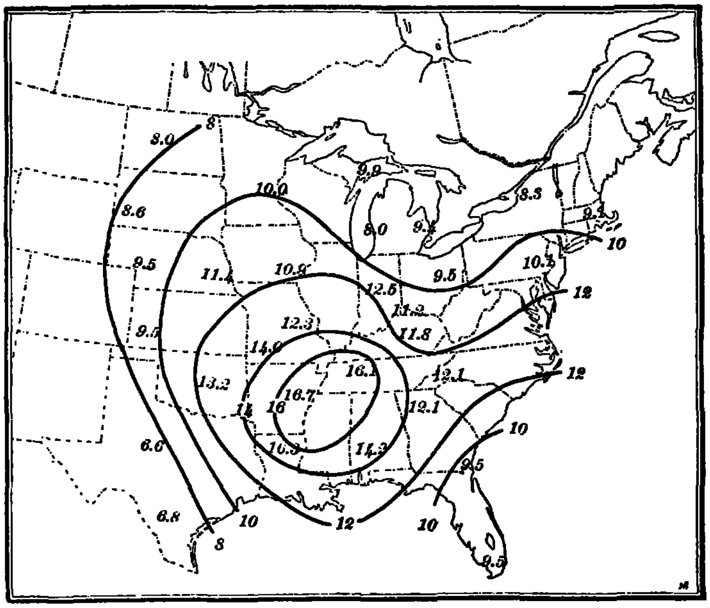

FIG. 13.—Average total rainfall (inches) between planting and digging early potatoes.

124 bushels per acre. With 20 inches the yield was 446 bushels, and with 40 inches it was 523 bushels per acre.

Actual rainfall.—The average amount of rainfall during the growth and development of the early potato crop is shown in figure 13 and for the late potato crop in

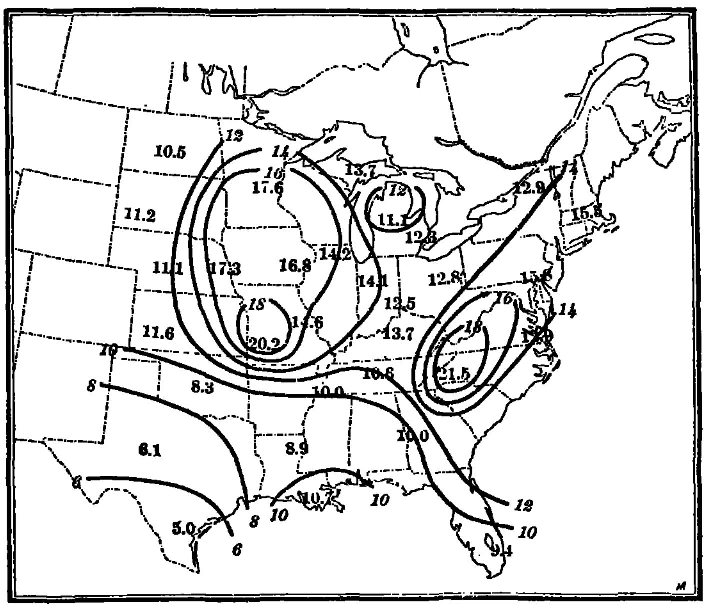

FIG. 14.—Average total rainfall (inches) between planting and digging late potatoes.

figure 14. In comparing these charts with those in figures 1 and 2 it will be seen that the best yield of potatoes is not where the greatest amount of rain falls.

TEMPERATURE REQUIREMENTS OF POTATOES.

The statements made in the first part of this article indicate that potatoes are a cool-weather crop, and studies which are elaborated later make this matter plain, but it seems wise at this point to refer to figures 15 and 16.

Thermal constants for potatoes.—The "thermal constant" of a crop is the average sum of the daily effective

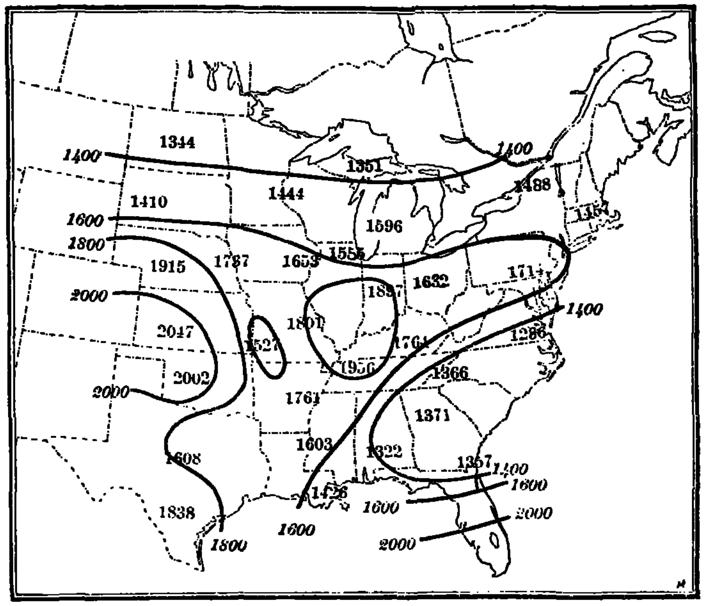

FIG. 15.—Average thermal constants between planting and digging early potatoes. (Figures state sums of daily mean temperatures above 43° F. during the growth and maturing of early potatoes.)

temperatures necessary to bring it to maturity. To determine the effective temperatures the writer has considered that part of the daily mean temperature

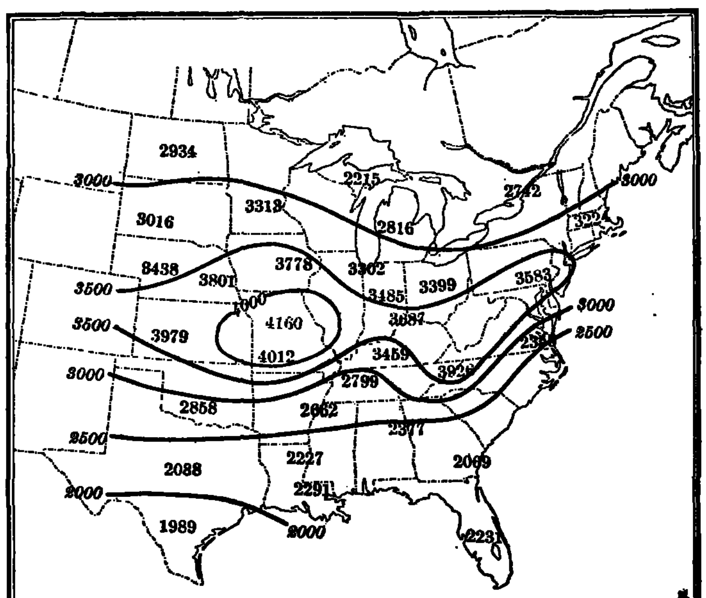

FIG. 16.—Average thermal constants between planting and digging late potatoes. (Figures state sums of daily mean temperatures above 43° F. during the growth and maturing of late potatoes.)

that is above 43° F. For example, a day with an average temperature of 48° has an "effective temperature" of 5°.

In figure 15 there is given the sum of the average daily degrees of heat above 43° between the date of planting and the date of harvesting of early potatoes. In figure 16 similar data are given for the late potato crop.

In general the greatest amount of heat necessary to grow and mature the potato crop is in that locality where the greatest amount of rain falls, and not necessarily where the time of growth is longest. The soil

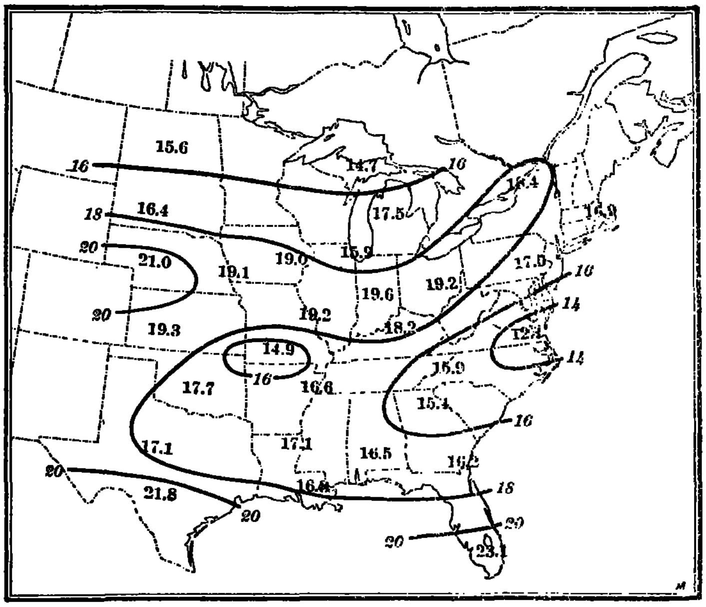

FIG. 17.—Average excess of the daily mean temperature over 43°F. between the planting and the digging of early potatoes.

moisture carries the plant food to the roots of a crop where it is utilized by solar energy. Other things being equal, the greater the moisture the greater the amount of energy necessary to work the plant food into vegetable tissue.

This is particularly emphasized in figures 17 and 18 which show the average excess of the daily mean tem-

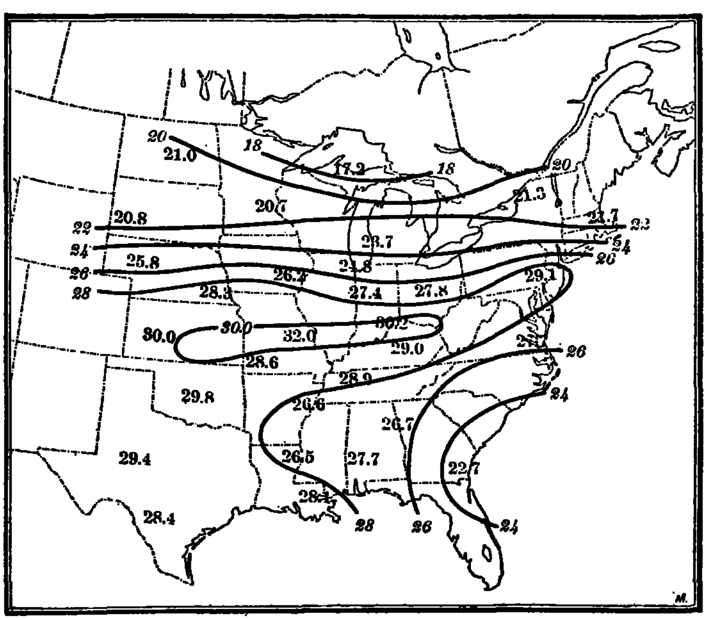

FIG. 18.—Average excess of the daily mean temperature over 43°F. between the planting and the digging of late potatoes.

perature over 43°F. for early and late potatoes, respectively. The daily amount of heat necessary for the potato crop is greatest in central districts where the rainfall is greatest. It is least in northern districts,

particularly for late potatoes, although the growing season is longer there.

Figures 19 and 20 show the percentage of possible sunshine that is experienced from planting to harvest-

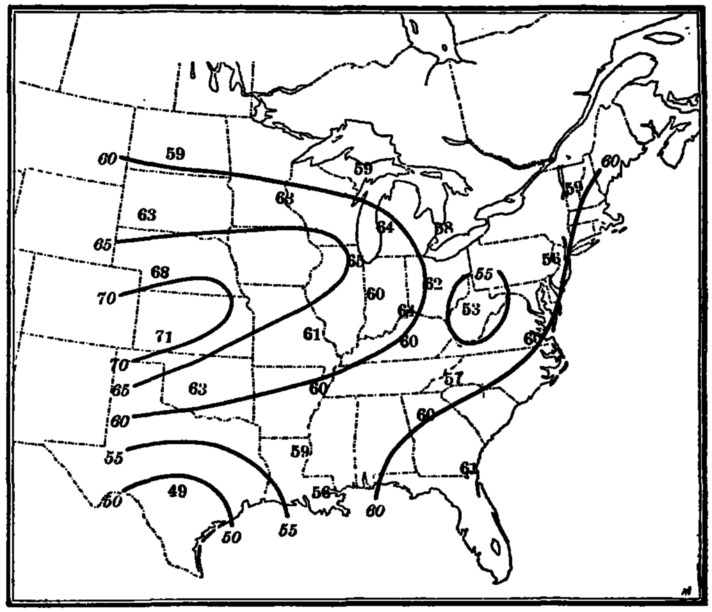

FIG. 19.—Percentage of possible sunshine between planting and digging of early potatoes.

ing of potatoes. A study of all of the charts giving the sunshine, temperature, rainfall, and number of days from planting to harvesting potatoes will give some interesting correlations. It is regretted that time will not allow for working out these data at this time for a larger number of stations and for all sections of the country.

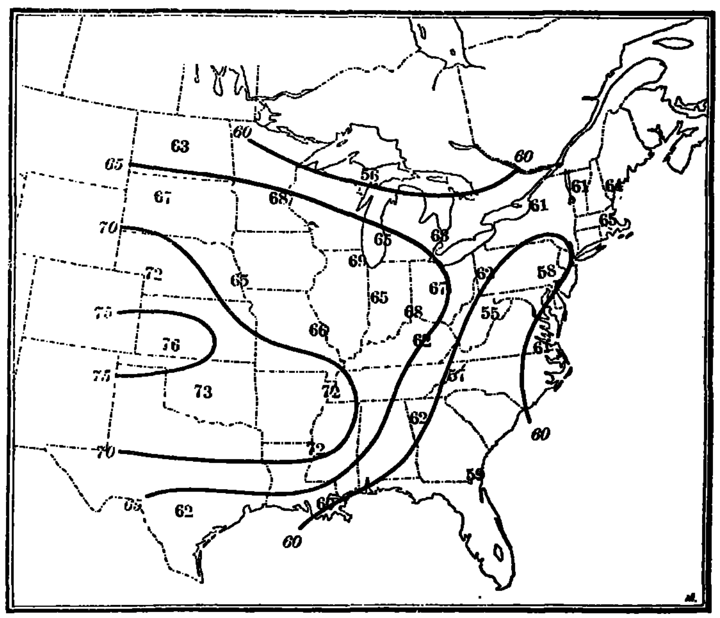

FIG. 20.—Percentage of possible sunshine between planting and digging of late potatoes.

CORRELATION OF WEATHER AND POTATO YIELD.

An early study.—In the MONTHLY WEATHER REVIEW for May, 1911, **39**: 792, the writer, in discussing the scientific method of correlation used the effect of the weather upon the yield of potatoes to illustrate the process. The period covered was from 1883 to 1909 and seemed to show that temperature had a greater effect on the yield in Ohio than rain, and that a cool summer was necessary for a good yield.

A 55-year correlation.—In Table 2 a correlation has been made between the mean temperature for July and the yield of potatoes in bushels per acre, in Ohio, for the period from 1860 to 1914, inclusive.

This method of correlation is described in the REVIEW referred to above and also in the MONTHLY WEATHER REVIEW for February, 1914. The method was developed by Bravais, Galton, Pearson, and Yule and shows the exact relation between two factors.

In this correlation the correlation coefficient, which is designated as r, is found by dividing the sum of the products of the departures of the data from the normal by the square root of the product of the sums of the squares of the departure values.

TABLE 2.—*Correlation of July temperature, and the yield of potatoes in Ohio, 1860 to 1914.*

Year.	July mean temperature.			Potato yield.			3×6.
1	2	3	4	5	6	7	8
	Mean.	Departure.	Square of departure.	Amount.	Departure.	Square of departure.	
	°F.	°F.		*Bushels.*			
1860	72.0	−1.6	2.56	97	+19	361	− 30.4
1861	70.2	−3.4	11.56	81	+ 3	9	− 10.2
1862	72.9	−0.7	0.49	64	−14	196	+ 9.8
1863	72.0	−1.6	2.56	66	−12	144	+ 19.2
1864	75.2	+1.6	2.56	74	− 4	16	− 6.4
1865	71.1	−2.5	6.25	66	−12	144	+ 30.0
1866	75.6	+2.0	4.00	70	− 8	64	− 16.0
1867	72.9	−0.7	0.49	66	−12	144	+ 8.4
1868	80.2	+6.6	43.56	72	− 6	36	− 39.6
1869	73.1	−0.5	0.25	85	+ 7	49	− 3.5
1870	76.4	+2.8	7.84	70	− 8	64	− 22.4
1871	72.2	−1.4	1.96	87	+ 9	81	− 12.6
1872	75.6	+2.0	4.00	74	− 4	16	− 8.0
1873	73.0	−0.6	0.36	76	− 2	4	+ 1.2
1874	75.0	+1.4	1.96	62	−16	256	− 22.4
1875	73.5	−0.1	0.01	96	+18	324	− 1.8
1876	75.6	+2.0	4.00	60	−18	324	− 36.0
1877	73.8	+0.2	0.04	82	+ 4	16	+ 0.8
1878	76.8	+3.2	10.24	65	−13	169	− 41.6
1879	75.9	+2.3	5.29	77	− 1	1	− 2.3
1880	73.1	−0.5	0.25	75	− 3	9	+ 1.5
1881	75.6	+2.0	4.00	39	−39	1,521	− 78.0
1882	70.7	−2.9	8.41	75	− 3	9	+ 8.7
1883	72.1	−1.5	2.25	99	+21	441	− 31.5
1884	71.5	−2.1	4.41	76	− 2	4	+ 4.2
1885	75.2	+1.6	2.56	82	+ 4	16	+ 6.4
1886	72.0	−1.6	2.56	86	+ 8	64	− 12.8
1887	77.9	+4.3	18.49	49	−29	841	−164.7
1888	72.1	−1.5	2.25	94	+16	256	− 24.0
1889	72.5	−1.1	1.21	81	+ 3	9	− 3.3
1890	73.0	−0.6	0.36	58	−20	400	+ 12.0
1891	69.0	−4.6	21.16	101	+23	529	−105.8
1892	73.0	−0.6	0.36	75	− 3	9	+ 1.8
1893	74.5	+0.9	0.81	69	− 9	81	− 8.1
1894	74.3	+0.7	0.49	64	−14	196	− 9.8
1895	71.6	−2.0	4.00	76	− 2	4	+ 4.0
1896	73.2	−0.4	0.16	84	+ 6	36	− 2.4
1897	75.5	+1.9	3.61	64	−14	196	− 26.6
1898	76.0	+2.4	5.76	86	+ 8	64	+ 19.2
1899	74.1	+0.5	0.25	78	− 1	1	− 0.5
1900	74.1	+0.5	0.25	86	+ 8	64	+ 4.0
1901	78.1	+4.5	20.25	72	− 6	36	− 24.0
1902	74.0	+0.4	0.16	93	+15	225	+ 6.0
1903	72.9	−0.7	0.49	91	+13	169	− 9.1
1904	71.4	−2.2	4.84	96	+18	324	− 39.6
1905	73.0	−0.6	0.36	83	+ 5	25	− 3.0
1906	72.1	−1.5	2.25	108	+30	900	− 45.0
1907	72.6	−1.0	1.00	86	+ 8	64	− 8.0
1908	73.9	+0.3	0.09	78	+ 0.1	....	....
1909	70.7	−2.9	8.41	96	+18	324	− 52.2
1910	73.8	+0.2	0.04	85	+ 7	49	+ 1.4
1911	74.0	+0.4	0.16	64	−14	196	− 4.8
1912	73.4	−0.2	0.04	101	+23	529	− 4.6
1913	74.5	+0.9	0.81	77	− 1	1	− 0.9
1914	74.0	+0.4	0.16	65	−13	169	− 5.2
Sum	....	....	232.64	....	....	10,179	−778.5
Mean	73.6	....	....	77.8	....	....	....

In this particular example the sums of the columns showing the squares of the departures from normal are 232.64 and 10,179 (see columns **4** and **7**). The product of these two sums equals 2,368,042.56. The square root of this product is 1,538.8. The sum of the values in column **8** is −778.5, and this divided by 1,538.8 gives a quotient of −0.51. This is the correlation coefficient, and shows the effect of the mean temperature for July upon the potato crop.

The nearer the correlation coefficient is to unity the closer the relation is between the two factors, and the nearer to zero the less the relation is. By the fact that the correlation coefficient is preceded by the minus sign it shows that the higher the temperature in July the smaller the potato crop.

It is believed that some relation is shown if the value of r is three times the probable error and that it is established without question if the coefficient is six times the probable error. The probable error is determined by the equation,

$$0.674\frac{1-r^2}{\sqrt{n}}$$

in which r is the correlation coefficient and n the number of years in the record. Substituting the above values in this equation the probable error is found to be ± 0.07.

The correlation coefficient from Table 2, −0.51, is therefore more than six times the probable error and establishes a marked relation between the mean temperature in July and the yield of potatoes in this State.

Effect of temperature by months.—A similar correlation between the potato yield in Ohio and the mean temperature of other summer and fall months has been made and is given in Table 3.

TABLE 3.—*Correlation of the mean temperature for Ohio for different periods, with the potato yield for the period 1860 to 1914.*

Periods.	Correlation coefficient.	Probable error.
	r	
May	−0.10	±0.09
June	−0.22	±0.09
July	−0.51	±0.07
August	−0.31	±0.08
September	−0.21	±0.09
October	−0.11	±0.09
June and July combined	−0.50	±0.07
July and August combined	−0.50	±0.07
June, July, and August combined	−0.49	±0.07

This indicates that while cool weather is more favorable than warm in each month considered, the temperature of either May, June, August, September, or October alone has very slight influence, as compared with July, upon the potato yield. Also that the temperature of June and July, July and August, or June, July, and August combined has just about the same effect as that for July alone.

An inspection of the figures showing the yield of potatoes, column **5** in Table 2, indicates an increase in the yield in recent years, and a calculation of the yield by 10-year periods shows a yield of 10 bushels per acre higher from 1900 to 1909 than the average for the whole period. Whenever there is a uniform increase or decrease in the yield of any crop it is always best, when making a correlation of this kind, to get the departure values from 10-year means. Such a correlation was made between the temperature for June and July combined and the yield of potatoes, using the 10-year departures, and the correlation coefficient was exactly the same as when the entire 55-year departures were used. Hence the longer period was used in all these calculations.

The length of time used in these correlations, the fact that the mean temperature was taken for the whole State, and the fact that the yield figures were from a crop fairly well distributed over the State, make the figures in Table 3 of marked value in showing the effect of the temperature of calendar months upon the yield of potatoes in this latitude.

Effect of rainfall upon potato yield.—On page 226 we discussed the water requirements of potatoes as shown by laboratory methods and on page 9 the actual rain that falls during the entire period of growth and development of the potato crop in different sections of the country. In Table 4 we shall show the effect of rainfall during different calendar months upon the potato yield as determined by the correlation method.

TABLE 4.—*Correlation of the rainfall for different periods with the potato yield in Ohio, for 1860 to 1914.*

Periods.	Correlation coefficient.	Probable error.
	r	
April	−0.21	±0.09
May	0.06	±0.10
June	0.10	±0.09
July	0.33	±0.08
August	0.22	±0.09
September	−0.13	±0.09
October	0.07	±0.10
July and August combined	0.37	±0.08

The low values for r in the above for May, June, September, and October indicate that the rainfall for those months alone has little effect upon the final yield of potatoes. April has a slight negative and August a slight positive correlation, although both are less than three times the probable error.

July, however, has a correlation coefficient four times the probable error, while that for July and August combined is nearly five times the probable error. This shows that July and July and August combined should have a moderate amount of rainfall, but it shows also that rain is not such a controlling factor as the temperature.

Combined effect of temperature and rain.—The effect of two weather factors upon the yield of a crop may be shown quickly and graphically by means of the "dot chart." This is illustrated by figures 21 and 22. In figure 21 the central horizontal line indicates the normal temperature for Ohio for the month of July. Parallel lines on either side of the normal correspond with degrees of temperature above and below the normal, respectively.

The central perpendicular line or axis of ordinates, indicates the average rainfall over Ohio in July for 55 years. The difference from the normal in inches and tenths is shown by parallel lines on either side. At the intersection of lines showing, respectively, the departure of the mean temperature and total rainfall for any particular July, a dot is placed to indicate the yield of potatoes for that year. If the yield was above the normal a plus mark is entered, and if the yield was below the normal then it is indicated by a minus sign. This makes plain the fact that warm and wet weather in July produces a bad effect upon the potato crop in practically every case. Also that warm and dry weather is generally unfavorable, although there may be a good yield if it is only moderately dry and warm. It shows also that cool weather is generally favorable, more especially if cool weather accompanies the wet weather. A cool and dry July has just as many yields above as below the normal.

In figure 22 the combined weather conditions for the months of July and August are indicated in the same manner. This emphasizes the fact that warm weather accompanied by dry weather for the whole two months is decidedly unfavorable, while good yields do sometimes result even with warm weather if there is a moderate amount of rain. Cool and wet weather for the two months is decidedly favorable.

The shifting of these plus and minus dots from one quadrant to another in these two charts indicates the accumulative effect of certain weather conditions. A condition that may not be injurious for four weeks becomes decidedly so if continued for eight weeks.

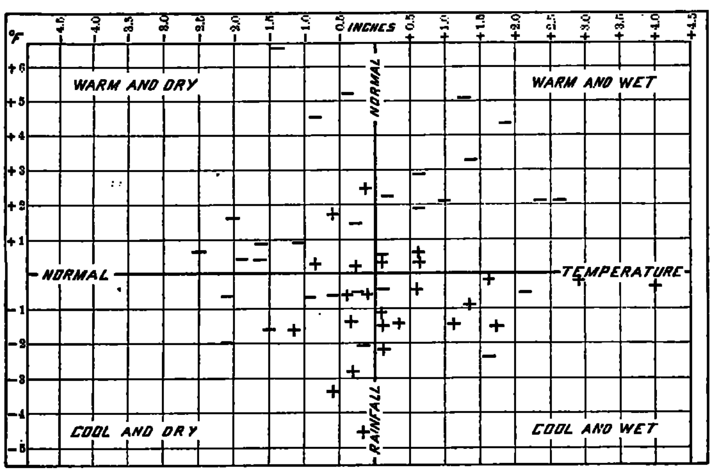

FIG. 21.—Chart showing the combined effect of temperature and rainfall during July upon the yield of potatoes in Ohio. (1860-1914, 55 years.) + Yield above normal; − yield below normal.

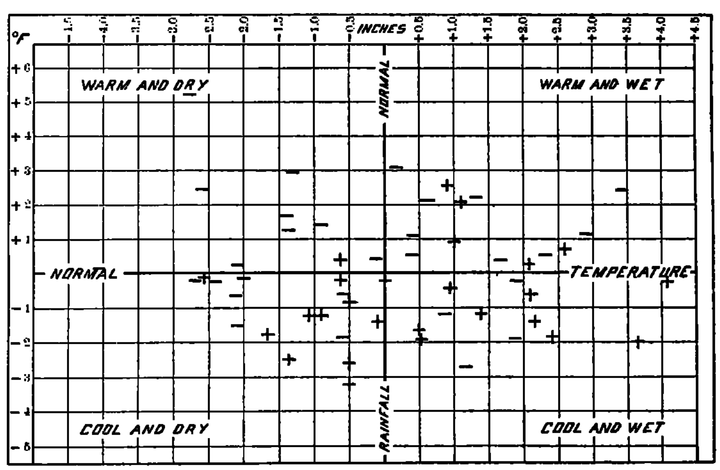

FIG. 22.—Chart showing the combined effect of temperature and rainfall during July and August upon the yield of potatoes in Ohio. (1860-1914, 55 years.) + Yield above normal; − yield below normal.

CORRELATION FOR SHORTER PERIODS THAN A MONTH.

As the average temperature and rainfall data for the State of Ohio are compiled by calendar months the correlation just discussed was confined to months or combinations of them. It seemed desirable, however, to ascertain whether there might not be shorter periods or a different grouping of the days that would affect the potato yield. To determine this the average yield of potatoes in the three counties of Franklin, Madison, and Pickaway, located in central Ohio, was computed for the period from 1891 to 1910, inclusive.

Rainfall for 10-day periods.—The rainfall for each 10 days was then averaged for some 18 different cooperative stations located in or near those counties. A correlation of the rainfall for periods of 10, 20, 30, 40, and 50 days from June 1 to August 31, with the potato yields, gives results as indicated by the following tables:

TABLE 5.—*Correlation between rainfall for 10-day periods and the yield of potatoes in central Ohio for the years 1891 to 1910.*

Period.	Correlation coefficient.	Probable error.
	r.	
June 1 to 10	0.29	±0.12
June 11 to 20	0.32	±0.12
June 21 to 30	0.16	±0.13
July 1 to 10	0.48	±0.10
July 11 to 20	−0.29	±0.12
July 21 to 31	−0.12	±0.13
Aug. 1 to 10	0.06	±0.13
Aug. 11 to 21	0.37	±0.11
Aug. 21 to 31	−0.26	±0.12

Only two of these values of r are more than three times the probable error, yet the table shows very interesting values. The first 10 days in July and the second 10-day period in August evidently should have rain to produce a good crop of potatoes, while there is a period between these days when rain seems to be detrimental.

Why is this? Is it because there are early and late crops growing at different seasons of the year? Or is there some other explanation?

While a correlation for a greater number of years might change these values slightly there is no question as to the reliability of the data for the time covered. The yield is an average for three counties and the rainfall figures are carefully determined from enough points to give the correct rainfall for these counties.

TABLE 6.—*Correlation of rainfall for 20-day periods with potato yield in central Ohio, 1891 to 1910.*

Period.	Correlation coefficient.	Probable error.
	r.	
June 1 to 20	0.48	±0.10
June 11 to 30	0.30	±0.12
June 21 to July 10	0.44	±0.11
July 1 to 20	0.03	±0.13
July 11 to 31	−0.23	±0.12
July 21 to Aug. 10	−0.08	±0.13
Aug. 1 to 20	0.29	±0.12
Aug. 11 to 31	0.22	±0.12

This correlation for 20-day periods shows the same favorable conditions for dry weather in July and the 1st of August, as was indicated in Table 5. The value of r for June 1 to 20 is almost five times the probable error, while from June 21 to July 10 it is four times the probable error. Other values of r are rather low.

TABLE 7.—*Correlation of rainfall for 30-day periods with potato yield in central Ohio, 1891 to 1910.*

Period.	Correlation coefficient.	Probable error.
	r.	
June 1 to 30	0.42	±0.11
June 11 to July 10	0.58	±0.09
June 21 to July 20	0.26	±0.12
July 1 to 31	0.002	±0.13
July 11 to August 10	−0.20	±0.13
July 21 to Aug. 20	0.19	±0.13
Aug. 1 to 31	0.11	±0.13

By this table the period from June 11 to July 10 is the most important as regards rainfall and rain is important during that time. Dry weather is most favorable from July 11 to August 10. The results from this table in particular substantiate those from Table 2.

TABLE 8.—*Correlation of rainfall for 40-day periods with potato yield in central Ohio, 1891 to 1910.*

Period.	Correlation coefficient.	Probable error.
	r.	
June 1 to July 10	0.59	±0.09
June 11 to July 20	0.35	±0.11
June 21 to July 31	0.09	±0.13
July 1 to Aug. 10	0.02	±0.13
July 11 to Aug. 20	0.02	±0.13
July 21 to Aug. 31	0.06	±0.13

Here rain is important during the period from June 1 to July 10, while there is little correlation between the rainfall, after June 21, for 40-day periods and the potato yield.

TABLE 9.—*Correlation of rainfall for 50-day periods with potato yield in central Ohio, 1891 to 1910.*

Period.	Correlation coefficient.	Probable error.
	r	
June 1 to July 20	0.44	±0.11
June 11 to July 31	0.20	±0.13
June 21 to Aug. 10	0.09	±0.13
July 1 to Aug. 20	0.17	±0.13
July 11 to Aug. 31	−0.05	±0.13

The correlation for the period from June 1 to July 20 is fairly high, but later 50-day periods are unimportant.

Temperature for 10-day periods and potato yield.—In the following tables the average temperature at Columbus, Franklin County, Ohio, is correlated with the yield of potatoes in Franklin, Madison, and Pickaway Counties:

TABLE 10.—*Correlation of mean temperature at Columbus, Ohio, for 10-day periods with potato yield in central Ohio, 1891 to 1910.*

Period.	Correlation coefficient.	Probable error.
	r	
June 1 to 10	−0.12	±0.13
June 11 to 20	−0.17	±0.13
June 21 to 30	−0.28	±0.12
July 1 to 10	−0.44	±0.11
July 11 to 20	−0.33	±0.12
July 21 to 31	−0.33	±0.12
Aug. 1 to 10	−0.23	±0.13
Aug. 11 to 20	−0.36	±0.11
Aug. 21 to 31	−0.38	±0.11

The highest correlation is −0.44 for the first 10 days of July. This value of r is just four times the probable error, and it shows plainly that potatoes in central Ohio should have cool weather at this time. By referring to Table 5 it will be seen that this same 10 days gave the highest correlation for rainfall and that wet weather is necessary.

These two tables establish the fact that cool and wet weather during the first 10 days of July is quite essential as far as central Ohio is concerned, and that the weather of this short period has a large influence upon the final yield of potatoes.

TABLE 11.—*Correlation of temperature for 20-day periods with potato yield in central Ohio, 1891 to 1910.*

Period.	Correlation coefficient.	Probable error.
	r	
June 1 to 20	−0.19	±0.13
June 11 to 30	−0.27	±0.12
June 21 to July 10	−0.61	±0.09
July 1 to 20	−0.54	±0.10
July 11 to 31	−0.41	±0.11
July 21 to Aug. 10	−0.42	±0.11
Aug. 1 to 20	−0.36	±0.11
Aug. 11 to 31	−0.43	+0.11

The 20-day period from June 21 to August 10 is the most important from a temperature point of view, and Table 6 shows that it should be wet as well as cool. The value of r for July 1 to 20 is almost six times the probable error.

TABLE 12.—*Correlation of temperature for 30-day periods with potato yield in central Ohio, 1891 to 1910.*

Period.	Correlation coefficient.	Probable error.
	r.	
June 1 to 30	−0.33	±0.12
June 11 to July 10	−0.53	±0.10
June 21 to July 20	−0.61	±0.09
July 1 to 31	−0.57	±0.09
July 11 to Aug. 10	−0.51	±0.10
July 21 to Aug. 20	−0.49	±0.10
Aug. 1 to 31	−0.35	±0.11

All values of r are three times the probable error and that for the two periods June 21–July 20 and July 1–31 is more than six times the probable error. These values of r for the three periods covering each of the full months of June, July, and August, comparing so closely with those for the State of Ohio for a much longer period as seen in Table 3 proves that the results from Tables 10 to 14, which are for a much shorter period and smaller area, are accurate.

TABLE 13.—*Correlation of temperature for 40-day periods with potato yield in central Ohio, 1891 to 1910.*

Period.	Correlation coefficient.	Probable error.
	r.	
June 1 to July 10	−0.58	±0.09
June 11 to July 20	−0.58	±0.09
June 21 to July 31	−0.62	±0.09
July 1 to Aug. 10	−0.63	±0.09
July 11 to Aug. 20	−0.54	±0.10
July 21 to Aug. 31	−0.51	±0.10

These values of r are all high and are about what one would expect from preceding tables.

TABLE 14.—*Correlation of temperature for 50-day periods with potato yield in central Ohio, 1891 to 1910.*

Period.	Correlation coefficient.	Probable error.
	r.	
June 1 to July 20	−0.58	±0.09
June 11 to July 31	−0.54	±0.10
June 21 to Aug. 10	−0.65	±0.08
July 1 to Aug. 20	−0.67	±0.08
July 11 to Aug. 31	−0.52	±0.10

Table 14 gives very little of value over Table 13. A study of the weather that is prevailing during any season with the requirements as shown by the preceding tables, would enable any potato grower to judge whether he may expect a good or a poor crop. If he will extend his observation over the county or the state or over an even larger district, he can make a good estimate of what the general yield will be.

WEATHER EFFECTS DURING DIFFERENT PERIODS OF DEVELOPMENT OF POTATOES.

Mr. Thomas Mikesell of Wauseon, Ohio, in Fulton County, has kept a very complete record[1] of phenological dates and data since 1883, and in Table 15 these data are given for early potatoes. It will be seen that the date potatoes are planted each year, is given as well as the date that the plant appears above the ground, the date in blossom, the date they are ready for use, and the date ripe.

In addition Mr. Mikesell recorded the potato yield in percentages of a "good crop" and the quality of the crop. As he is a very careful observer the data are reliable. Mr. Mikesell has compiled the same data for late potatoes and from his tables it appears that the average date for planting late potatoes is May 19, the average date that they appear above the ground, May 31, average date in bloom, July 7, and the average date ripe, September 8.

TABLE 15.—*Phenological dates and data for growth of early potatoes at Wauseon, Ohio, 1883 to 1912, by Thomas Mikesell.*

[Lat., 41° 35′ N.; long., 84° 07′ E.; alt., 780 feet A. M. S. L.]

Year.	Date planted.	Date above ground.	Date in bloom.	Date ready for use.	Date ripe.	Per cent of good crop.	Quality of crop.
1883*	Apr. 12	May 8	June 10	June 30	Aug. 20	....	....
1884	21	14	18	July 2	July 30	....	....
1885	23	19	25	9	31	....	....
1886	22	9	12	June 24	20	85	Good.
1887	26	11	18	30	25	100	Do.
1888	23	18	20	July 10	Aug. 8	70	Do.
1889	22	11	21	June 27	15	95	Do.
1890	25	13	14	22	July 28	50	Fair.
1891	24	11	17	June 29	Aug. 7	95	Good.
1892	28	14	20	July 1	15	90	Do.
1893	24	15	16	5	1	60	Do.
1894	17	1	8	June 25	1	60	Do.
1895	27	7	17	July 10	20	60	Do.
1896	May 1	12	14	June 19	8	100	Do.
1897	6	20	25	July 10	July 28	60	Do.
1898	21	30	29	30	Aug. 20	....	....
1899	Apr. 25	6	10	June 20	5	80	Good.
1900	28	....	....	....	....	....	....
1901	17	....	June 20	....	....	....	....
1902	21	....	8	June 23	....	....	....
1903	....	....	May 28	....	....	....	....
1904	May 5	May 17	June 20	....	Sept. 12	75	Good.
1905	4	10	6	June 27	Aug. 25	80	Do.
1906	Apr. 24	10	11	July 3	Sept. 1	80	Do.
1907	May 4	14	18	7	Aug. 20	45	Do.
1908	Apr. 22	10	8	12	1	50	Do.
1909	May 5	12	8	3	5	60	Do.
1910	Apr. 8	8	18	10	20	85	Do.
1911	May 4	25	24	8	July 28	40	Fair.
1912	Apr. 16	9	16	June 28	25	75	Good.
Average	Apr. 26	May 13	June 15	July 2	Aug. 9	72	....

* Data for the years 1883 to 1901, inclusive, apply to Mr. Mikesell's own farm; data for 1902 to 1912 apply to certain nearby fields, the same field being used for the entire season.

Weather constants and development of potatoes.—At the same time that Mr. Mikesell kept the data shown in Table 15 he recorded the daily temperature and rainfall from reliable and well-exposed instruments. We have therefore tabulated the total number of days, total "effective temperature," and total rainfall for each year in Table 16. Unfortunately most of the data for crop develop-

[1] See Monthly Weather Review Supplement No. 2. Washington, D. C., 1915.

ment were not observed during the years 1900 to 1903; hence the constants data are omitted for those years.

It will be seen that Table 16 contains the thermal and rainfall constants and the total number of days between each period of development as noted in Table 15, as well as the totals of these factors from planting to ripening of early potatoes. The highest and lowest total values are printed in distinctive type.

The total number of days from planting to ripening will be found to vary from 83 to 134, the total "effective temperature" from 1,908 degrees to 3,149 degrees, and the total rainfall from 5.5 inches to 23.9 inches. The average number of days is 106, average thermal constant 2,414 degrees, and the total average rainfall 12.6 inches. There seems to be no very close relation between the totals of these three different constants for different years. The heat necessary to develop the plant seems to be the most constant from year to year.

TABLE 16.—*Constants during the growth of potatoes at Wauseon, Fulton County, Ohio, 1883 to 1912.*

Year.	Time.					Total effective temperature.				Total rainfall.			
	From planting to above ground.	From above ground to bloom.	From above ground to ready for use.	From bloom to ripe.	From planting to ripe.	From planting to above ground.	From above ground to bloom.	From bloom to ripe.	From planting to ripe.	From planting to above ground.	From above ground to bloom.	From bloom to ripe.	From planting to ripe.
	Days	*Days*	*Days*	*Days*	*Days*	*° F.*	*° F.*	*° F.*	*° F.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1883	26	33	53	71	130	215	502	1,737	2,454	1.0	6.7	10.8	18.5
1884	23	35	50	42	100	272	764	1,163	2,199	2.6	2.9	5.0	10.5
1885	26	37	51	36	99	244	836	1,090	2,170	3.4	6.9	3.2	13.5
1886	17	34	46	38	89	242	630	1,036	*1,908*	1.4	2.3	1.8	*5.5*
1887	15	38	50	37	90	243	906	1,311	2,460	1.3	4.7	4.4	10.4
1888	25	33	53	47	105	269	731	1,418	2,418	2.0	2.3	4.0	8.3
1889	19	41	47	55	115	273	707	1,455	2,435	0.1	11.4	6.8	18.3
1890	18	32	40	44	94	143	680	1,177	2,000	5.5	1.6	4.0	11.1
1891	17	37	49	51	105	200	720	1,349	2,269	0.8	3.2	4.4	8.4
1892	16	37	48	56	109	171	746	1,617	2,534	7.4	10.4	6.1	**23.9**
1893	21	32	51	46	99	153	675	1,378	2,206	5.2	3.9	5.2	14.3
1894	14	38	55	54	106	183	553	1,738	2,474	2.4	4.0	3.1	9.5
1895	10	41	64	64	115	240	868	1,976	3,084	1.2	1.8	2.5	*5.5*
1896	11	33	38	55	99	285	749	1,617	2,651	0.7	4.9	13.7	19.3
1897	14	36	51	33	*83*	234	678	1,031	1,943	2.0	3.3	4.6	9.9
1898	9	30	61	52	91	188	801	1,570	2,559	0.7	3.6	6.7	11.0
1899	11	35	45	56	102	275	729	1,653	2,647	1.0	4.1	5.2	10.3
1900	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1901	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1902	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1903	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1904	12	34	.....	83	129	148	687	2,075	2,910	0.6	3.3	8.0	11.9
1905	6	27	48	80	114	64	422	2,178	2,664	1.0	6.8	9.5	17.3
1906	16	32	54	82	130	151	718	2,280	**3,149**	0.9	3.0	10.2	14.1
1907	10	35	54	63	108	103	480	1,717	2,400	0.5	5.9	6.3	12.7
1908	18	29	63	54	101	124	665	1,507	2,296	1.8	4.9	7.7	14.4
1909	7	27	52	58	92	76	495	1,532	2,103	2.4	3.5	7.6	13.5
1910	30	41	63	63	**134**	202	593	1,841	2,636	5.8	2.6	6.4	14.8
1911	21	30	44	34	85	505	802	963	2,270	0.5	3.9	6.5	10.9
1912	23	38	50	39	100	223	723	1,062	2,008	1.7	6.1	1.7	9.5
Average	**17**	**34**	**50**	**55**	**106**	**209**	**687**	**1,518**	**2,414**	**2.1**	**4.5**	**6.0**	**12.6**

A correlation of constants and yield.—A tabular correlation between the thermal constants and the yield of potatoes as reported by Mr. Mikesell is given in Table 17.

TABLE 17.—*Correlation between thermal constants and potato yield, Wauseon, Ohio, 1883 to 1912.*

Period.	Correlation coefficient.
	r.
From date of planting to date above ground	0.03
From date above ground to date of bloom	0.24
From date of bloom to date ripe	0.16
From date planted to date ripe	0.25
For 10 days before blooming	0.17
For 10 days after blooming	−0.30

The most important value of r in this table is that for the 10 days after blooming when cool weather is desirable. This, however, is not over three times the probable error, so that too much weight must not be given to the result.

Unfortunately, we do not have the blooming dates for central Ohio; but if the time from planting to blooming for late potatoes is the same in central Ohio as at Wauseon, the 10-day after-blooming period would agree closely with some of the highest 10-day correlations, as shown in Table 10. This, after taking into account the difference in date of planting between Wauseon and Columbus.

TABLE 18.—*Correlation between rainfall and potato yield, Wauseon, Ohio, 1883 to 1912.*

Period.	Correlation coefficient.
	r
For 10 days before planting	0.02
From date planted to date above ground	−0.06
From date above ground to date in bloom	0.33
From date in bloom to date ripe	0.18
For 10 days before blooming	0.09
For 10 days after blooming	−0.07

The only value of r to be considered in Table 17 is for the period between the date that potatoes come up and the date that they are in bloom.

If the time between the date of planting and the dates that they appear above the ground and the date they are in bloom is the same for late potatoes at Columbus as at Wauseon, Ohio, then the time for the highest value of r in Table 18 agrees very closely with the next to the highest value for r in Table 6 and is not far from the time of the highest in Table 7.

The cumulative evidence is that the most important time for rainfall for potatoes, so far as these correlations show, is before blooming.

In Colorado it was found that with thorough cultivation, potatoes planted the first of May needed irrigation seldom until July. Also that one should not irrigate after August 10, so as to give 50 to 60 days for ripening in dry earth.

In Wisconsin it was found that one of the secrets of irrigation of potatoes was not to irrigate until after the young tubers had set. When irrigated immediately before setting a greater number of potatoes were formed than the plant can properly support and mature. In Utah it was found that increased irrigation increased the starch content and decreased the protein content of potatoes.

In 1914 a yield of 110 bushels of potatoes was produced on one-eighth of an acre of land in Fremont County, Idaho. This is at the rate of 880 bushels per acre and is reported to be the highest yield ever produced in this country. The date of planting was not given in the article that came under the observation of the writer, but the potatoes came up about the first of June. The first irrigation was given July 20 and the last September 7. By October 15 the crop had matured, and on October 20 it was harvested.

A study of the preceding tables will show the best time during the growth of the potato plant to apply water in irrigation, and also whether a given rain can be used to best advantage by the plant.

OTHER INVESTIGATIONS.

In Portage County, Ohio.—In the spring of 1914 Mr. H. A. Stevens, a student in agricultural meteorology at the Ohio State University, investigated the relation between the weather and the yield of potatoes in Portage county. The period covered was from 1884 to 1913.

Mr. Stevens states that while Portage County has a wide variety of soils most of the potatoes are grown on sandy lands. Also that most of the commercial growers raise late potatoes and plant them very late, although they are practically all in the ground by July 1. Portage County is in the best potato-growing district of northeastern Ohio.

Mr. Stevens found little or no correlation between the yield of potatoes and either the temperature or the rainfall of June, July, or September. During the month of August, however, he found rainfall and high temperature both to be favorable. The correlation coefficient for the rainfall for August and the yield of potatoes was 0.26, and that for the temperature and the yield was 0.44. This value of r for the temperature is six times the probable error and for rainfall slightly less than three times the probable error.

The present writer has since correlated temperature and rainfall with the potato yield in Portage County, covering a period of 54 years, without finding a high correlation between the temperature of any particular month or group of months and the yield. Table 19 shows the results of this calculation.

TABLE 19.—*Correlation of the average temperature with potato yield in Portage County, Ohio, 1860 to 1913.*

Period.	Correlation coefficient.
	r.
April	0.13
May	0.06
June	0.19
July	−0.14
August	0.14
September	−0.22
October	−0.02
June and July combined	−0.04
July and August combined	−0.12
June and July with July reversed	0.20
July and August with July reversed	0.22

Inasmuch as the potatoes are planted so late one would expect no correlation between the temperature of either April, May, or June, and the yield. The plus value of r for August, even though slight, in this correlation and the higher value in Mr. Steven's calculation are not what we would expect from other tables.

At Wauseon in northwestern Ohio the average number of days between planting and blooming of late potatoes is 49. If it takes about the same length of time in Portage County from planting to blooming this would bring the critical period for temperature sometime in August when the average temperature for the whole month would cover the time before blooming when warm weather seems desirable, and after blooming when it should be cool. This would in part explain the failure to find a correlation between the average temperature for a complete month and the yield.

TABLE 20.—*Correlation of the rainfall with potato yield in Portage County, Ohio, 1860 to 1913.*

Period.	Correlation coefficient.
	r.
June	−0.23
July	0.06
August	0.38
September	−0.03

In this table there is a fairly high value of r for the August rainfall.

Correlation in Licking County.—In the spring of 1914 Mr. Paul Geiger, another student in agricultural meteorology at the Ohio State University correlated the weather with potato yield in Licking County in central Ohio. His results are given in Table 21.

TABLE 21.—*Correlation of the temperature and the rainfall with the yield of potatoes in Licking County, Ohio, 1884 to 1913.*

Period.	Correlation coefficient.	
	Temperature.	Rainfall.
	r.	r.
May	−0.02	0.02
June	−0.48	0.38
July	−0.35	0.21
August	−0.27	−0.34
September	−0.02	−0.17
October	−0.04	−0.14
June and July combined	−0.59	0.41
July and August combined	−0.87	* 0.18
August and September combined	−0.27	−0.12
June, July, and August	−0.55	0.35
July, August, and September	−0.38	* −0.24

* Departure sign for July reversed.

In the calculation for Table 21 Mr. Geiger used 10-year means in both yield and weather data before getting the departure values, because the yield of potatoes has increased in recent years. In the calculations in Table 22 the present writer has covered a longer period and has obtained the departure from a mean for the whole 54 years.

TABLE 22.—*Correlation of the temperature with the potato yield in Licking County, Ohio, 1860 to 1913.*

Period.	Correlation coefficient.
	r.
April	−0.01
May	0.06
June	−0.29
July	−0.36
August	−0.28
September	−0.23
October	−0.15
June and July combined	−0.44
July and August combined	−0.44
August and September combined	−0.15

The value of r for June and July combined and for July and August combined is almost six times the probable error and agrees very closely with the same periods in Table 3 for the whole State. These last tables merely emphasize the facts brought out in the earlier ones and add to the weight of evidence that cool summers produce the best yields of potatoes in this latitude.

Studies in Michigan.—During the present semester at the Ohio State University, Mr. Edward B. Scott, a special student in agricultural meteorology, is studying the effect of the weather upon the potato yield in the State of Michigan. His period covers from 1887 to 1914, inclusive, and the data are for the whole State.

His work is not complete at time of writing, but for the month of July he finds the value of r in a correlation between temperature and yield to be −0.543, or five times the probable error. For the month of August it is 0.05, for September 0.15, and for July and August combined −0.345.

This value of r for July agrees with the studies in Ohio. Studies similar to these should be made in other States, particularly those where potatoes are grown so extensively as in northern New England and New York.

By a comparison of the facts given in the preceding pages with the mean monthly temperature and monthly distribution of rainfall charts, as published by the United States Weather Bureau, one can determine whether any given locality is favorable for potato culture. One can determine also when they should be planted so as to bring wet or dry periods in proper sequence in the growth and development of the potato plant.

SEED POTATOES.

It is customary to consider northern-grown potatoes more suitable for planting than those grown in the neighborhood or farther south. This matter is discussed in the Ohio Agricultural Experiment Station Bulletin 218 and the conclusion is reached that far northern-grown potato seed is not superior to Ohio-grown seed, if our home-grown seed is well preserved.

The following is quoted from that bulletin: "The reason that northern-grown stock has come to be noted for its superiority for a more southern latitude is because the seed is wintered in a lower degree of temperature in the more northern sections; it is kept sound and hard, crisp, fresh, and dormant and comes down to us at or just previous to planting time in this most desirable condition."

Farmers' Bulletin 386 states that uniform growth without check in development produces seed potatoes of high vitality. This bulletin states also that there is danger of using varieties that set a larger number of tubers than can be developed unless moisture is plentiful at just the right time.

Climate and weather should be studied.—This raises the point that the seasonal distribution of rainfall must be studied to see that it does come at the right period in the growth of the potato plant. Before planting the seed the weather of the period when it was completing its development should be carefully studied to see that the plant had the proper distribution of heat and moisture to enable it to have "uniform growth without check in development."

Are the best seed potatoes immature?—The question has been raised as to whether northern-grown seed is not better because the potatoes were dug before they were quite ripe, and thus keep "more crisp, fresh, and dormant," and can be shipped south in this most desirable condition. This matter should receive the attention of experiment station investigators.

DISEASES OF POTATO PLANTS.

The foliage of the potato plant is particularly subject to diseases which are affected by weather conditions to a marked degree.

Early blight, tip-burn, and the *Fusarium* dry-rot are dry-weather diseases while late blight develops in wet and cool weather in some districts and in wet and hot weather in others. Sun scald occurs when bright and hot weather follows suddenly a moist and cloudy period.

Other diseases such as brown-rot, rosette, potato wilt, and dry end rot affect the foliage in particular sections of the country, and it seems probable that a further study of these will show that most of them are more or less severe under certain weather conditions.

The early blight of the foliage, due to the attacks of the fungus, *Alternaria solani*, develops most rapidly in dry weather and seems to be rather characteristic of dry warm soils.

Tip-burn is a physiological disease which may follow a long period of hot, dry weather and is really a scorching of the tips of the leaves due to lack of moisture. This disease is most apt to occur after blooming.

The dry-rot of potatoes, which is a well-known storage trouble, has been found to be due to a fungus of the genus *Fusarium* variously designated as *Fusarium oxysporum* and *Fusarium solani*. This disease is manifest in the field with most varieties of potatoes by a partial wilting, an inward and upward turning of the leaves, and a changing to a sickly yellow. It seems quite apparent that drought hastens the yellowing symptoms of the disease, whatever effect this has upon the activity of the fungus causing the disease.

Late blight.—The so-called "late blight" of potatoes is the most serious of all potato diseases and is due to the fungus *Phytophthora infestans*. The potato rot resulting from this disease caused very great loss in eastern North America in 1842, 1845, and 1874, and there was a general outbreak in New England and New York in 1901, 1902, and 1903. In 1845 the disease spread through Great Britain, Ireland, and Belgium, and the terrible Irish famine of that year was due to the almost total loss of the potato crop of Ireland from this disease during the preceding summer.

This disease is undoubtedly favored by moist weather. Rainfall apparently has much to do with the spread of the disease, particularly if heavy rain is followed by cloudy weather and still air, when the moisture would cling to the leaves for a long time. If the rainfall is followed by clear skies and sufficient wind to quickly evaporate the moisture from the potato leaves, then the disease would be checked.

Effect of temperature on late blight.—Writers in some parts of the country state that late blight will develop with a spell of *warm*, moist, "muggy" weather, while in other sections it will be noted that a serious outbreak of late blight has followed a period of *cool*, moist weather.

In Bulletin 245 of the United States Bureau of Plant Industry the following statement is made as to the effect of temperature upon *Phytophthora infestans:*

> Exposing test-tube cultures for 10 minutes at temperatures up to 40° C. did not prevent the later development of the fungus; beyond this temperature inhibition resulted. Where cultures were held at constant temperatures the best growths resulted between 16° and 19°C. (60.8° and 66.2°F.). Below 16°C. the growth was slower, and below 5°C. (41°F.) it was wholly inhibited. At and above 23°C. (73.4°F.) the growth was inhibited, with no sporulation above 25°C. (77°F.) and no vegetative growth at or above 30°C. (86°F.).

Prof. A. D. Selby, in the Ohio Naturalist for February, 1907, quoting from Scribner, says: "A temperature ranging from 65° to 75°F. produces conditions favorable for the disease"; and quoting from Galloway: "A daily mean or normal temperature of from 72° to 74°F. for any considerable time, accompanied by moist weather, furnishes the best conditions for the spread of the disease."

It should be noted that while the authors quoted above do not agree as to the most favorable temperatures for the spread of late blight, in one instance the writer refers to tests made under *constant* temperatures while the other two refer to *mean daily* temperatures, when the temperature would be higher than the optimum in the daytime and lower in the nighttime.

It is probable, therefore, that the most favorable open-air temperature condition is when the mean daily temperature is between 70° and 74°F. Also that the development of the disease is checked if the mean daily temperature is above 75° F. for a few days, and that the spores are killed at a temperature of 77° to 80° F.

Temperature terms are relative.—In figure 23 there has been entered the highest mean daily temperature during the warmest part of the year at each of the Weather Bureau stations. Isothermal lines have been drawn for each 5 degrees.

This chart shows that in extreme northern parts of the country and in the higher parts of the Rocky Mountain States the mean summer temperature is generally too low for the best development of late blight in potatoes and that practically all of the central and southern districts are too warm for the disease to get a foothold.

This makes plain also why in Maine late blight is a disease of "warm" moist weather, while in Ohio it is spoken of as a disease of "cool" moist summers.

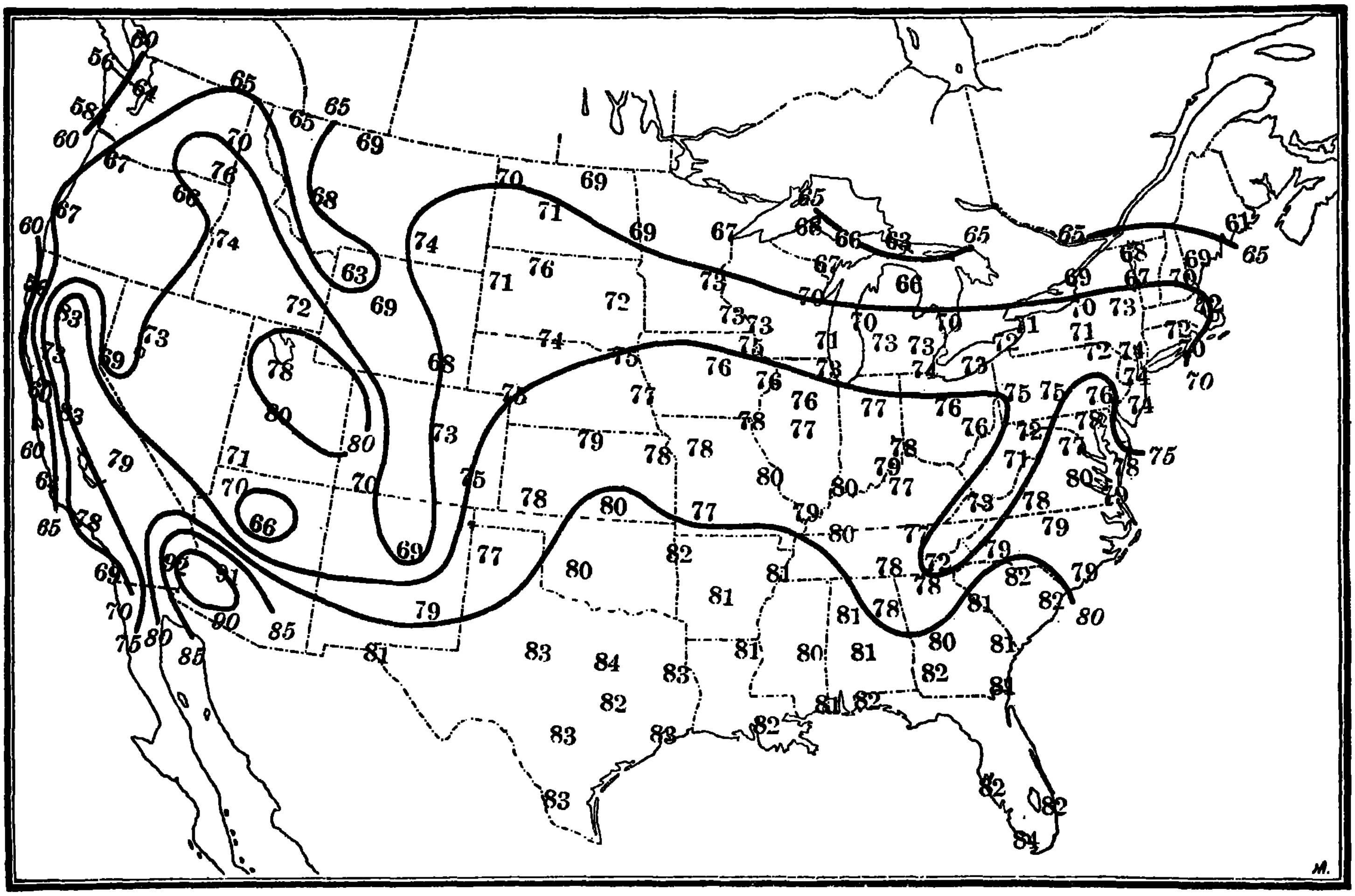

FIG. 23.—Highest mean daily temperature (°F.) during the warmest part of the season.

An inspection of the yearly temperature records would show that north of this normal temperature line of 70° there are seasons or periods when the temperature is high enough to cause an outbreak of the late blight, and that even south of the line of 75° a season might be cool enough to cause loss to the potato crop. The critical district would be along the line of 70°, as shown on this chart.

It must be remembered that in the southern portion of this critical area it would take more than a few weeks of cool weather to develop the disease and that even one cool season would hardly do it. But that with a series of cool summers it might become sufficiently developed to cause serious damage, so that even with a cool and moist summer which we have found favorable for the growth of potatoes there might result a very poor yield, due to loss by late blight. Then one warm and dry season, although unfavorable for the yield of potatoes, would yet kill out the *Phytophthora* so effectually that it would take another series of cool years for it to become again established.

CONCLUSION.

This paper is submitted, not with the feeling that it is without criticism or entirely without error or that the last word has been said upon the subject of the effect of weather upon the yield of potatoes—indeed, there are several different lines of investigation that it suggests and that might well be carried out—but rather with the hope that its presentation may encourage others to delve into this almost completely neglected but wonderfully interesting and thoroughly economical and important field of science. The United States Weather Bureau, at its regular and cooperative stations, has accumulated a vast amount of meteorological and climatological data; the various State boards of agriculture and the United States Department of Agriculture have compiled records of crop production for a long period of years. It only remains for plodding investigators to put these data together and develop a live and practical *agricultural meteorology*.

REFERENCES.

Bailey, Solon I. Peruvian Meteorology. Annals, Astron. Obsy, Harvard College, **39**, pt. 3.

Briggs & Shantz. The Water Requirements of Plants. (U. S. Bureau of Plant Industry, Bull. **284, 285.**)

Jones, L. R., *and others.* Investigations of the potato fungus *Phytophthora infestans.* (Bureau of Plant Industry. Bull. **245.**)

Selby, A. D. On the occurrence of *Phytophthora infestans* and other diseases. Ohio Naturalist, February, 1907.

Ward, Robert DeC. Climatic notes made during a voyage around South America. (Monthly Weather Review?)

Wood, Chas. D. Potato Culture. New Jersey State Board of Agriculture, Thirty-sixth Annual Report, 1909.

U. S. Department of Agriculture. Farmers' Bull. **386.**

Ohio Agricultural Statistics, 1912–13.

Ohio Agricultural Experiment Station. Bulletins **218** and **229.**

Vermont Agricultural Experiment Station. Bulletin **159.**

Wyoming Agricultural Experiment Station. Bulletin **67** and Press Bulletin.

United States Department of Agriculture. Yearbook, 1913.

ICE CONDITIONS IN DANISH WATERS, 690–1860.[1]

We have very striking reports from the times of the fourteenth and fifteenth centuries concerning the freezing over of the Baltic (Ostsee) and even of the "Skagerrak" or the North Sea (German Ocean). These reports have been so positive that many have believed them to be undeniable evidence of a change in natural conditions since those times; that they indicate either a warming of the climate or, as Pettersson has suggested, an increase in the depth of the less salty superficial stratum of the Baltic waters with a resultant intensification in the vertical circulation, so that the winter cooling is at present distributed throughout a greater water mass than formerly.

The author of this first attempt at a comprehensive study of the ice conditions in Danish waters during historic times reaches another conclusion, however. After ten years of searching—at first it seemed like searching for a needle in a haystack—the author seems to have exhausted all existing material. His general result is that the ice conditions have not altered demonstrably during historic times. Not until recent years has there been any essential change, and the recent failures to form firm ice bridges are due to the disturbing steamship traffic.

The occasions when, in the years 1635 and 1709, persons walked across the ice bridge from the island of Bornholm to Sweden or Rügen were reported as very remarkable events; the conditions recurred in 1838 and had it not been for the steamboats, would have returned in 1893. The reported earlier "lively travel" on the ice may be compared with similar reports in recent years, e. g.—the report by Ritzau's Bureau on March 18, 1909, concerning traffic across the "Kleinen Belt" (strait between Schleswig-Holstein and the Island of Fünen), upon investigation turned out to have been based upon the fact that two men dared to walk across and a number of children played near the shore. One is all the more justified in assuming similar exaggerations in earlier times also, since among the reports are some demonstrably false ones. General statements such as "the Baltic was frozen over," "the Black Sea was frozen over," may with certainty be interpreted as applying to individual bays only.

In part, however, this unreliability of the records is due to special causes. Thus the names of the bodies of water about Denmark have suffered changes, in part. As late as the 18th century the waters off Copenhagen were not called The Sound [Sund], but the Baltic (Ostsee), the Kattegat was called the Skagerrak, and sometimes the Kattegat was even called the North Sea. Very often, also, a copyist has interchanged the figures when writing a year; for example, different sources of information have written 1292, 1294, 1296, and 1269, when the correct year was 1296; similarly, 1320, 1323, and 1333 should all read 1323. That New Years falls in the wintertime also often causes uncertainty regarding the year number.

The principal source of information for the years since 1750 has been the Berlingske Tidende. Between 1750 and 1799 The Sound [Sund] was full of ice in 29 years, and in 10 of those years it was possible to cross the [Sund] on the ice. From 1800 to 1849 the [Sund] was full of ice in 19 years, and in 9 years it was crossable. After 1850 the increasing steamer traffic made such comparisons impossible; nevertheless even to-day traffic on Danish waters is interrupted by ice in one year out of three. Also ice-conditions reports have been instituted seven times by the Danish Meteorological Institute. At the beginning of winter heavy frosts have no effect in forming ice, because at that season the water is still too warm; ice forms only in long or late winters. In hard winters, to-day as in earlier times, the waters begin to freeze about the first of February and remain frozen until the middle of March. As early as the 16th century navigation used to open in March, the buoys were set out about March 1 and the lights re-lit.

There has been no noticeable change in all these features since certainly as early as the 15th century. Conditions of these waters since 1860 will be discussed in a later study.

[1] **Speerschneider, C. J. H.** Om isforholdene i Danske farvande Aarene 690–1860. Kopenhagen, 1915. 141 p. Plate. (Dans. meteorol. Instit., Public., Mitt. 2.) *Translated from* abstract by V. Köppen in Met. Ztschr. apr. 1915, 32: 188–9.)